

OHIO UNIVERSITY

School of Electrical Engineering & Computer Science

**Performance of IEEE 802.16
OFDMA Standard Systems in
Airport Surface Area Channels**

1-3 May 2007

Indranil Sen, Beibei Wang, David W. Matolak
School of Electrical Engineering & Computer Science
Ohio University
Athens, OH 45701

Outline

- Introduction/background
 - Importance of performance evaluation for airport surface channels
 - Growing significance of 802.16
- Channels
 - Description of channels considered
 - Comparison highlights of stationary and non-stationary channel models for different airports
- 802.16e system description
- Numerical results for 802.16e performance
 - BER for different channel estimation schemes
 - Throughput using “aggressive scheduling”
- Summary & future work



Airport Surface Channels

- Motivation
 - Civilian aviation anticipates both a near and long-term need for new communications capabilities
 - MLS extension band, 5.091-5.15 GHz, primary candidate for deploying new communication system for airport surface
- ACAST Channel Characterization project
 - Measurement campaigns at several airports (CLE, MIA, JFK, Tamiami, Burke Lake, and OU), 2005-06
 - Stochastic channel models developed to emulate the physical propagation environment
 - Channel models useful to simulate different system performance under realistic conditions

802.16e Features

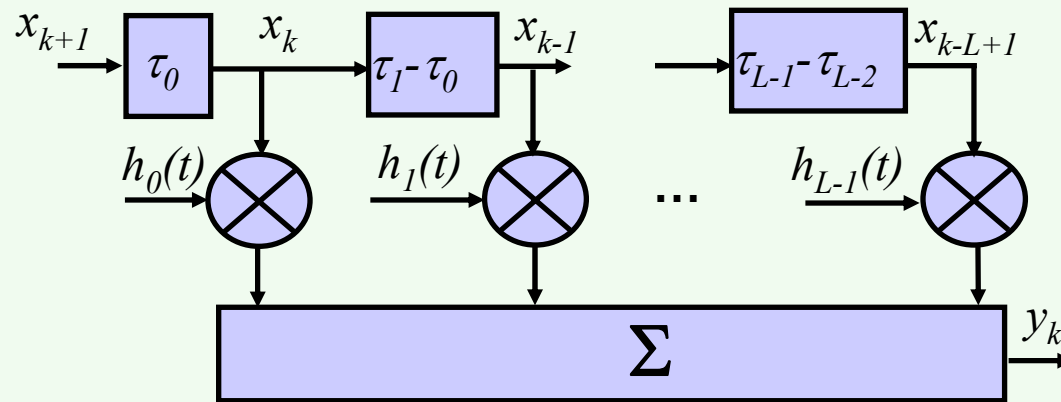
- Designed for NLOS applications
- OFDMA-based, with scalable channel bandwidth
- High throughput
 - Up to 100 Mbps for 20 MHz channel bandwidth
- Large coverage area
 - Up to 50 km for stationary case (directional antennas)
- Quality of service (QoS) support
 - Different service levels
 - Grant/request based MAC
- Mobility support

Airport Environment Description

- Airport surface area classification
 - **LOS-O**: Open areas, e.g., runways, some taxiways
 - **NLOS-S**: mostly NLOS w/dominant Specular component plus low energy multipath components, e.g., near terminals
 - **NLOS**: obstructed LOS, largest DS, e.g., near gates
- Aircraft inhabit all three regions—non-stationary channel, in contrast to most terrestrial models
- We focus on “worst case” models
 - Large Airport NLOS model
 - Medium Airport NLOS model
 - Small Airport NLOS-S model

Tapped Delay Line Channel Model

- Tapped delay line structure



$$h_k(t) = z_k(t) \alpha_k(t) e^{j\phi_k(t)}$$

– Weibull *pdf* for $\alpha_k(t)$: $p_w(r) = \frac{\beta}{a^\beta} r^{\beta-1} \exp\left[-\left(\frac{r}{a}\right)^\beta\right]$

β : shape factor; determines fading severity

a : scale factor $= \sqrt{E(r^2) / \Gamma([2 / \beta] + 1)}$

- $z_k(t)$ is a 2-state, first-order Markov model

Criteria for Channel Models

- Number of taps (L)
 - Criterion 1: *Mean RMS delay spreads* $L = \lceil E[\sigma_\tau] / T_c \rceil$
 - Criterion 2: *Maximum duration* of the CIR
- Aggregate energy
 - Criterion 1: For NLOS, 95% aggregate energy
 - Criterion 2: All the taps, i.e., 100% aggregate energy
- Non-Stationary/Stationary
 - Criterion 1: Persistence process and correlation among taps
 - Criterion 2: No Persistence process, uncorrelated taps

Different Channel Models

- Model -1 (M1)
 - Number of taps: *Mean RMS-DS*
 - Aggregate Energy: 95%
 - Non-Stationary channel model
- Model -2 (M2)
 - Number of taps: *Maximum duration* of CIR
 - Aggregate Energy: 100%
 - Non-Stationary channel model
- Model -3 (M3)
 - Number of taps: *Maximum duration* of CIR
 - Aggregate Energy: 100%
 - Stationary channel model

Example Model [M1, Large Airport, 10]

Tap Index k	Energy	β_k	$P_{1,k}$	$P_{00,k}$	$P_{11,k}$
1	0.6350	2.10	1.0000	NA	1.0000
2	0.0641	1.58	0.8794	0.1975	0.8899
3	0.0363	1.56	0.7890	0.3258	0.8197
4	0.0323	1.61	0.7747	0.3301	0.8051
5	0.0285	1.63	0.7519	0.3363	0.7809
6	0.0278	1.57	0.7437	0.3599	0.7794
7	0.0265	1.60	0.7288	0.3789	0.7690
8	0.0236	1.67	0.7102	0.4013	0.7556
9	0.0226	1.66	0.7060	0.4063	0.7529
10	0.0207	2.0	0.6930	0.4324	0.7488
11	0.0223	1.65	0.7065	0.4052	0.7528
12	0.0219	1.66	0.7000	0.3868	0.7374
13	0.0192	2.0	0.6798	0.4453	0.7386
14	0.0194	2.0	0.6992	0.4067	0.7449

- Tap amplitudes specified by energy, β
- Persistence parameters specified by Markov probabilities

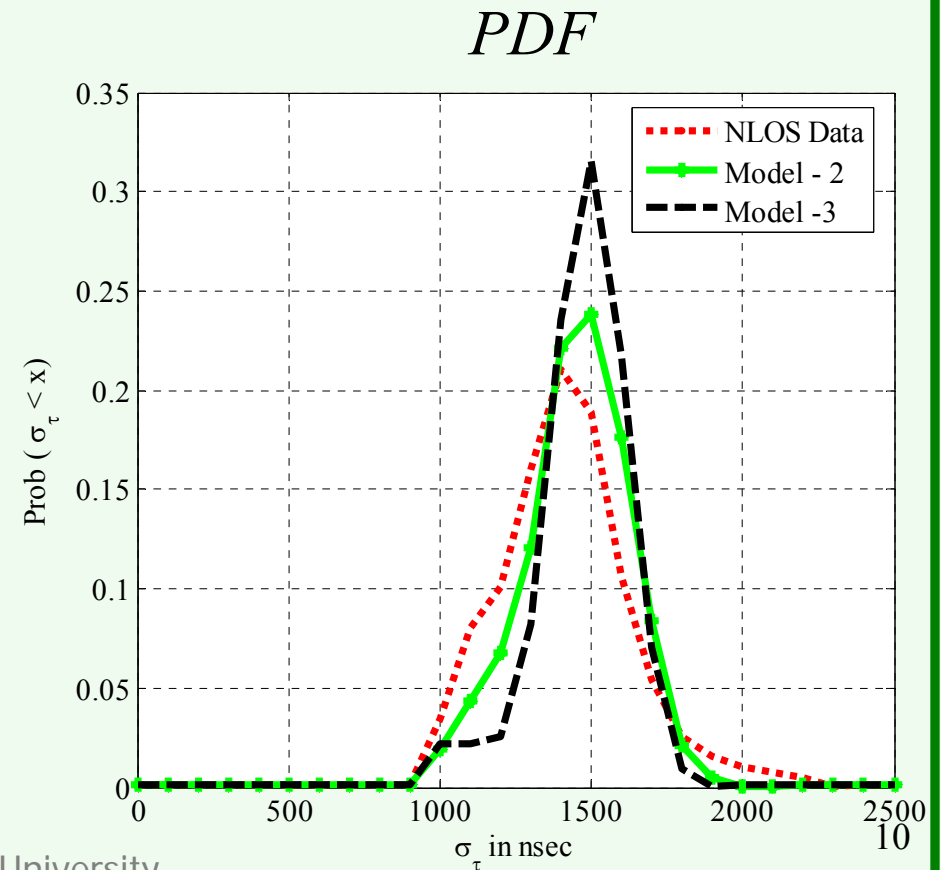
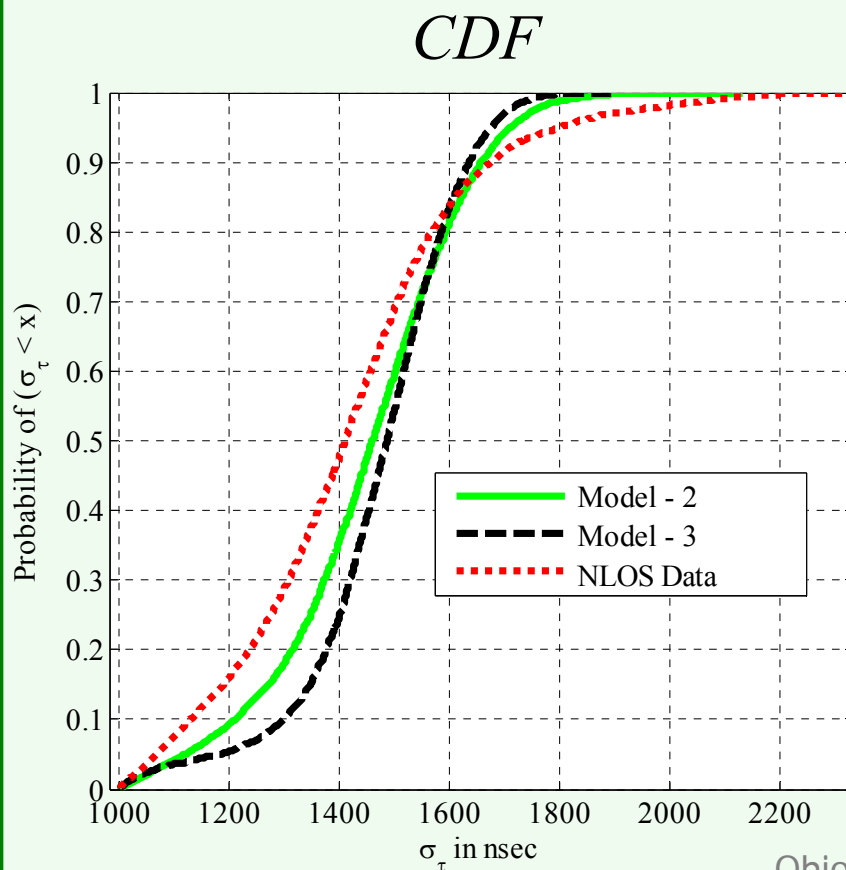
$$TS_k = \begin{bmatrix} P_{00} & P_{01} \\ P_{10} & P_{11} \end{bmatrix}$$

$$SS_k = \begin{bmatrix} P_0 \\ P_1 \end{bmatrix}$$

$P_{i,j}$ = probability of transition from state i to state j

Comparing Models with Data

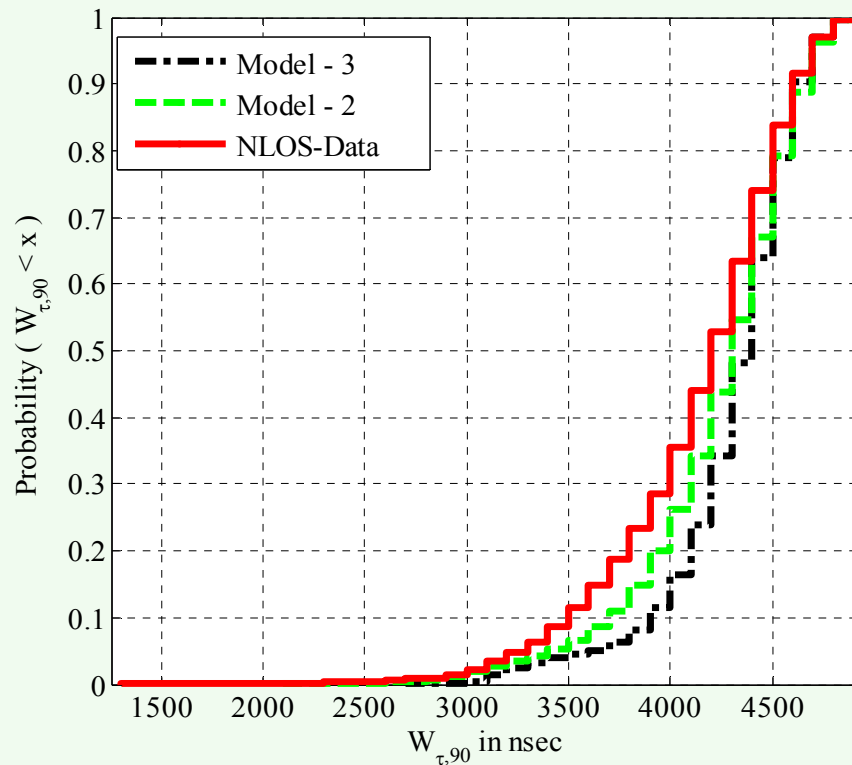
- Comparison of RMS-DS statistics for Model-2, Model-3 w/those of data for [Large Airport, 10 MHz, NLOS]



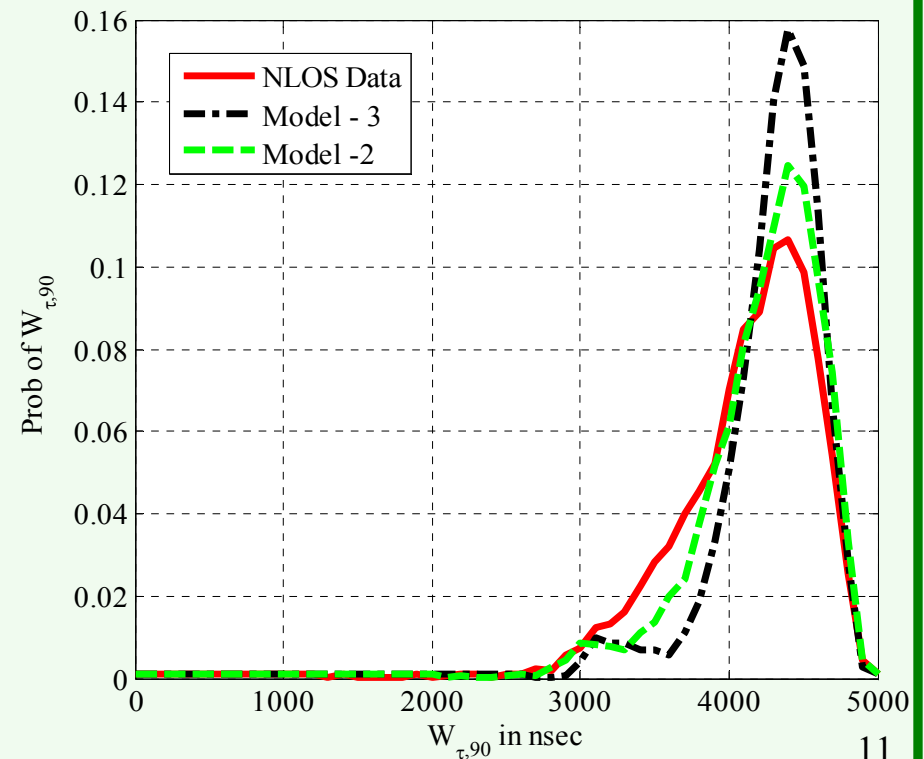
Comparing Models with Data (2)

- Comparison of Delay Window statistics for Model-2, Model-3 w/those of data for [Large Airport, 10 MHz, NLOS]

CDF



PDF



Comparing Models with Data (3)

- “Distance” measures to compare *pdfs* of models and data
 - Measured data denoted D , simulated model denoted S
 - Kullback-Leibler (KL) & Histogram Intersection (HI)

$$KL = \sum_{i=1}^M D_i \log_2 \left(\frac{D_i}{S_i} \right); \quad \text{KL} = 0 \text{ is perfect match}$$

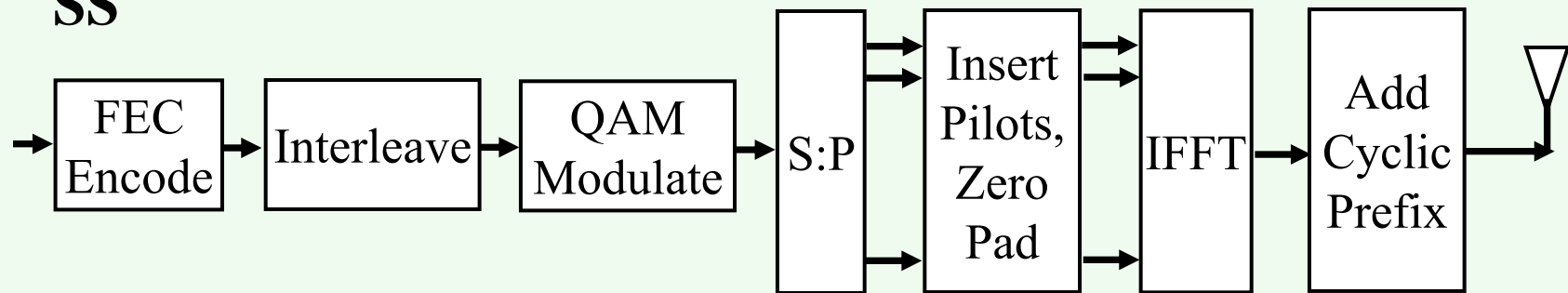
$$HI = \sum_{i=1}^M \min(D_i, S_i); \quad \text{HI} = 1 \text{ is perfect match}$$

Large Airport-NLOS					Medium Airport-NLOS				Small Airport-NLOS-S			
	σ_τ		$W_{\tau,90}$		σ_τ		$W_{\tau,90}$		σ_τ		$W_{\tau,90}$	
	KL	HI	KL	HI	KL	HI	KL	HI	KL	HI	KL	HI
Model-2	0.15	0.85	0.052	0.92	0.24	0.78	0.27	0.80	0.55	0.79	0.65	0.63
Model-3	0.41	0.74	0.21	0.82	0.36	0.73	0.31	0.76	1.24	0.55	1.14	0.55

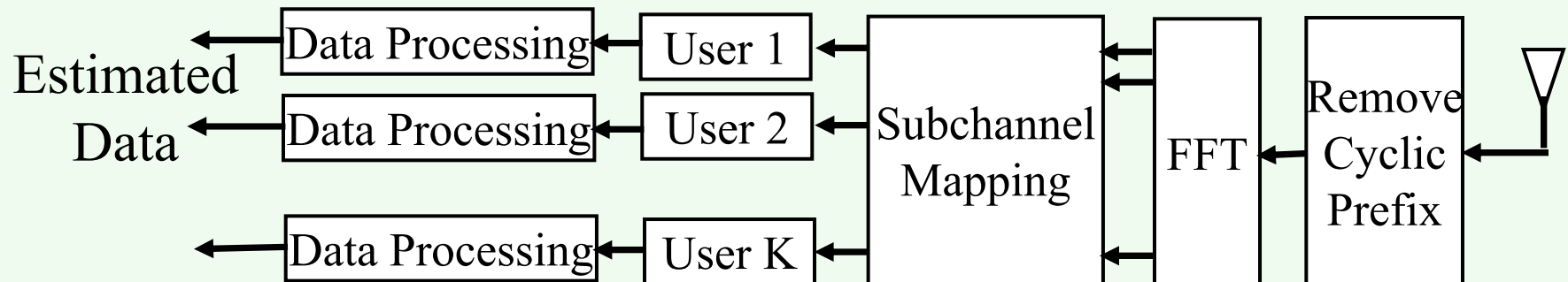
Communication System Description

802.16e system structure (from SS to BS)

SS

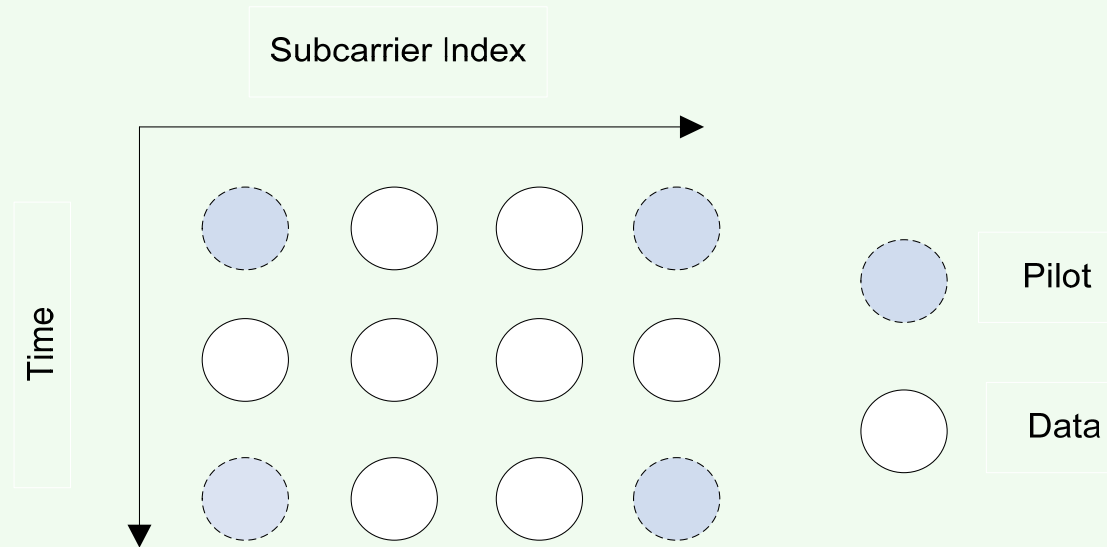


BS



Communication System Description (2)

- 802.16 defined subcarrier allocation algorithms
 - Distributed permutation (PUSC/FUSC), mandatory
 - AMC permutation, optional

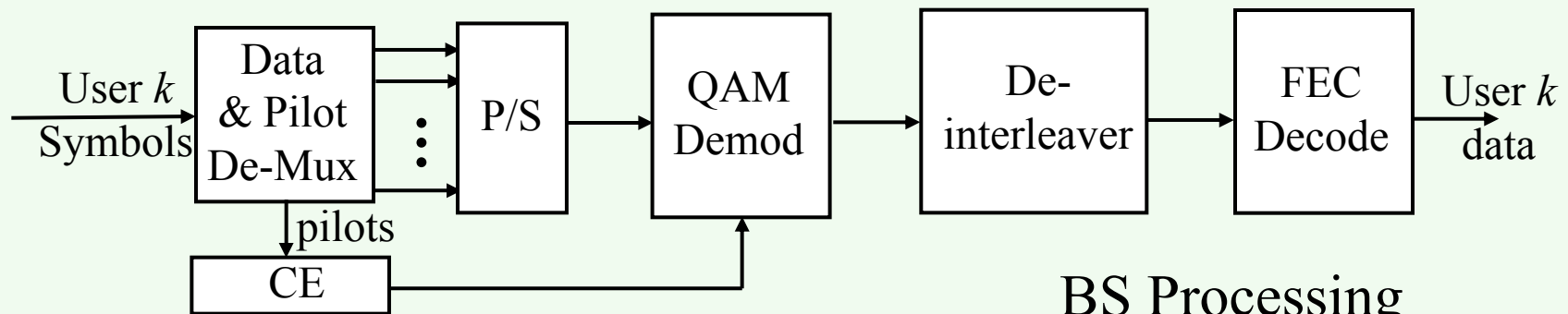


Uplink PUSC tile structure

Each subchannel in uplink PUSC has six distributed tiles, determined by the permutation defined in 802.16

Channel Estimation Techniques

- As with many wireless standards, 802.16 does not specify receiver processing
- One key algorithm is channel estimation (CE)
 - CE 1: average pilot symbols in both T & F domains
 - CE 2: average pilot symbols in T domain, and linearly interpolate in F domain
 - CE 3: linearly interpolate the pilot symbols in both T & F domains



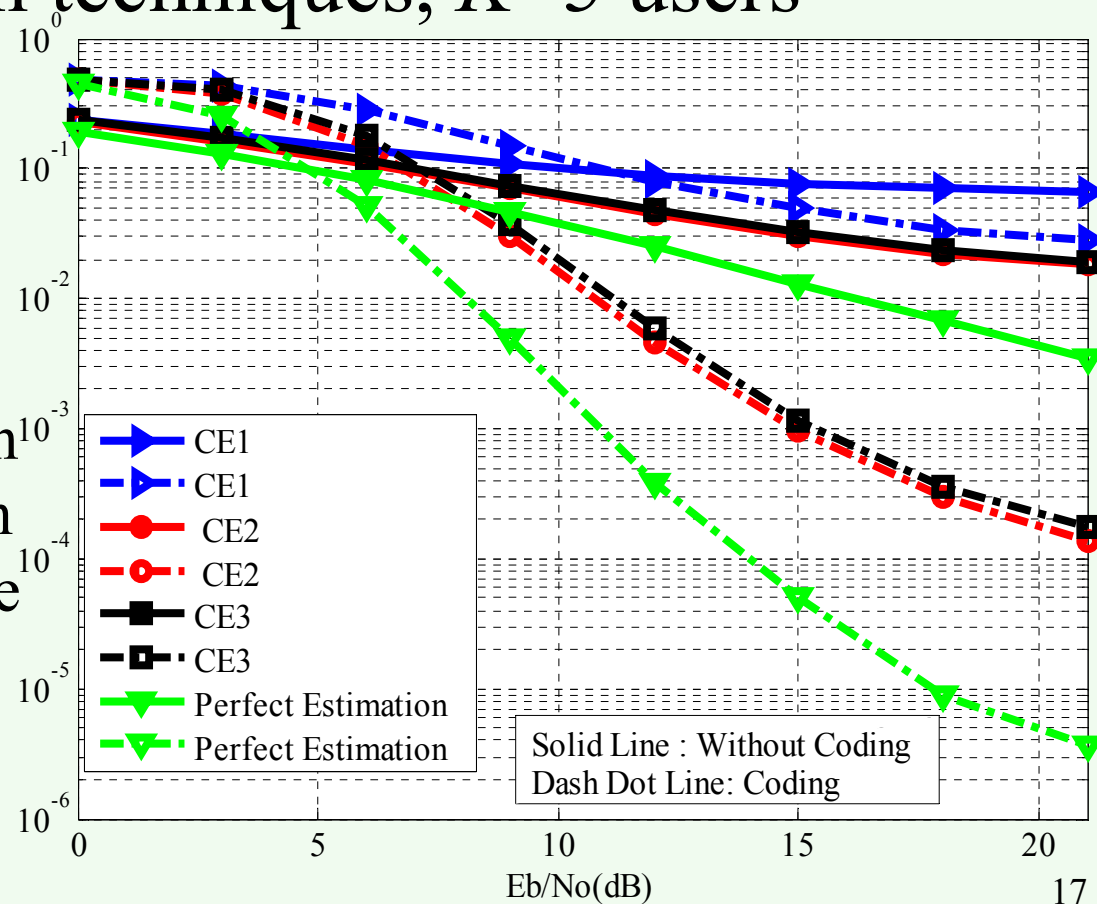
OFDMA System Parameters

Channel Bandwidth (MHz)	8.75
FFT size N	512
Useful OFDMA Symbol Period T_b (μs)	51.2
CP Duration (μs)	1.6
OFDMA Symbol Period T_s (μs)	52.8
Maximum Channel Delay Spread T_M (μs)	1.4
Number of Channel Taps	14
Doppler Frequency f_D (Hz)	120
Number of Users	5

BER Performance

- BER vs. E_b/N_0 , large airport NLOS M2 channel, different estimation techniques, $K=5$ users

- $N = 512, f_{D,max} = 300$ Hz
- All channel estimators have worse performance than perfect estimation
- $P_b = 3 \times 10^{-3}$ at 21 dB with perfect channel estimation highlights degradation due to the severe frequency selectivity of the large airport channel

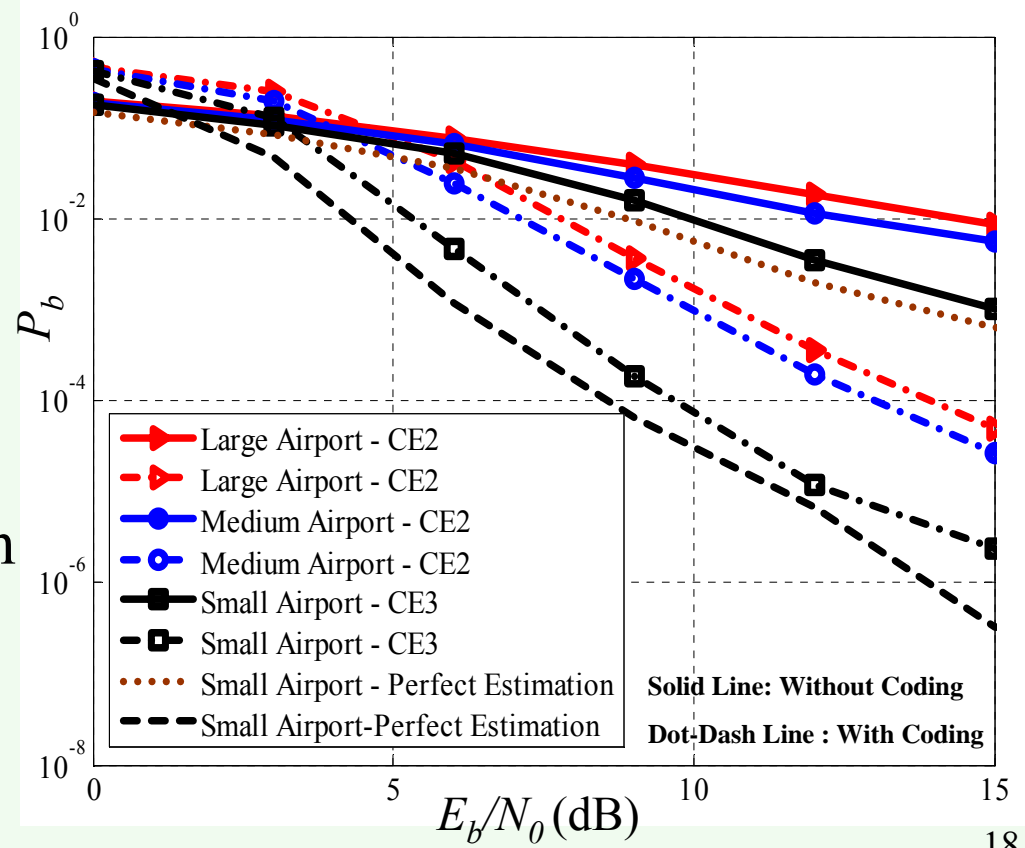


BER Performance

(2)

- BER vs. E_b/N_0 for all airports using model M1 and best estimation techniques, $K=5$ users

- $N = 512, f_{D,max} = 300$ Hz
- Performance best for Small Airport NLOS-S
- Performance worst for Large Airport NLOS
- BER performance for Small Airport NLOS-S with perfect channel estimation acts as a lower bound

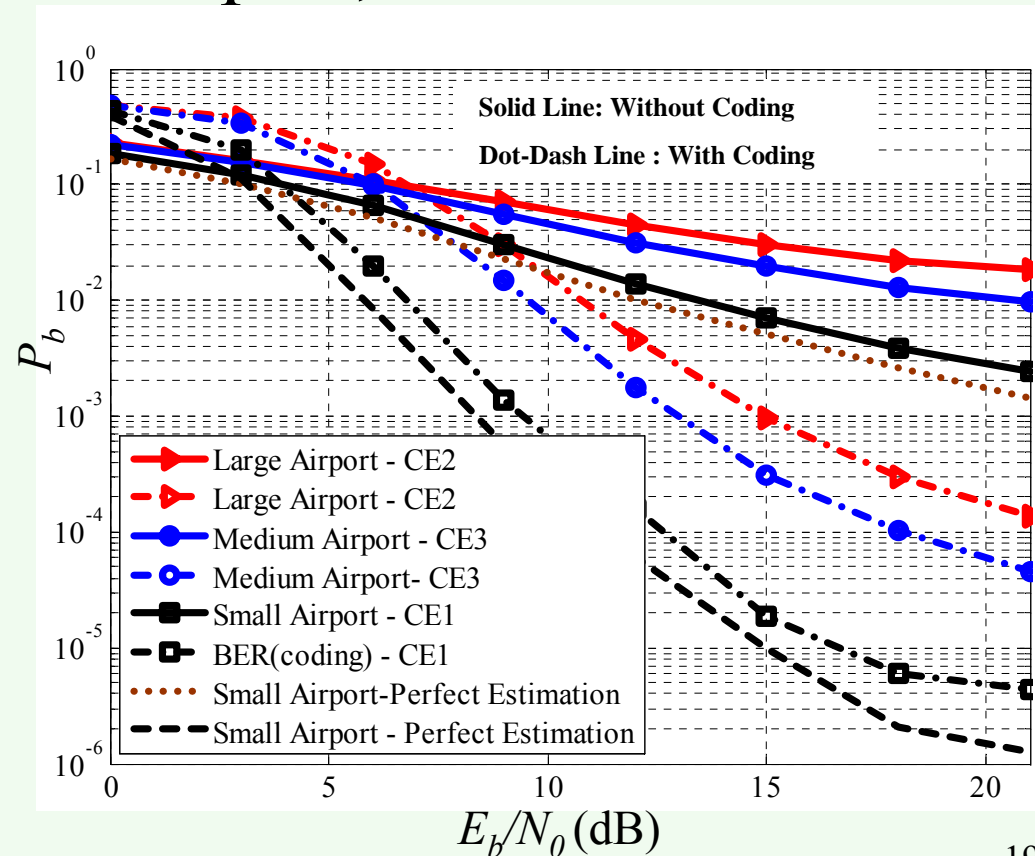


BER Performance

(3)

- BER vs. E_b/N_0 for all airports using model M2 and best estimation techniques, $K=5$ users

- $N = 512, f_{D,max} = 300$ Hz
- Performance best for Small Airport NLOS-S
- Performance worst for Large Airport NLOS
- BER performance for Small Airport NLOS-S with perfect channel estimation acts as a lower bound



OFDMA Scheduling Parameters

Parameters for Two Service Classes

	GP User	BE User
Required BER	10^{-2}	10^{-2}
Required Data Rate R_b (Mbps)	2	Not Guaranteed
Number of Users	First 50%	Last 50%

- QoS defined by (uncoded) error probability $\leq 10^{-2}$
- User classes
 - Guaranteed performance (GP)
 - “Best effort” (BE)
- For GP users, BER takes priority over data rate
 - Data rate limited if BER requirement can not be met

“Aggressive” Scheduling Algorithm

For each GP user:

- a) Find the best available subcarrier
- b) Determine modulation scheme $m_{k,n} = \lfloor \log_2(1 + \gamma_{k,n} / \Gamma) \rfloor$;
if no modulation scheme can satisfy BER
requirement, scheduling considered done for this user
- c) Repeat a), b) until the data requirement is satisfied

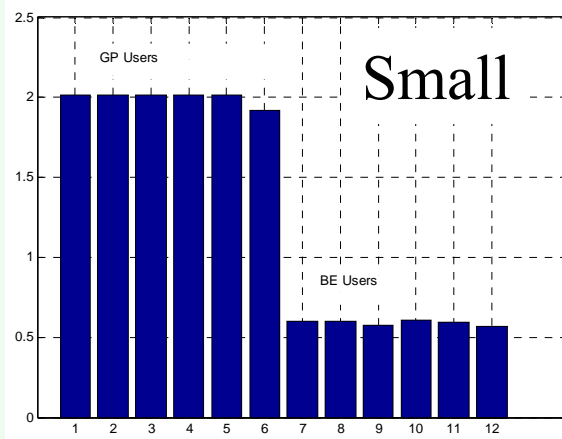
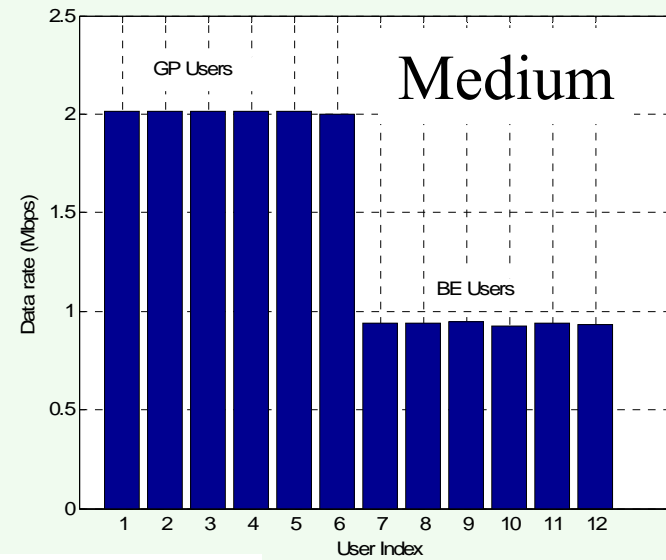
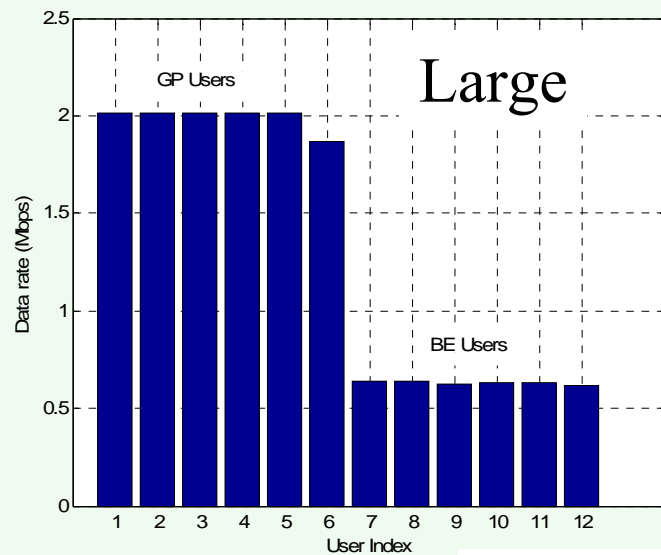
For each BE user:

- d) Find best available subcarrier for the user with lowest
data rate, and determine the corresponding
modulation scheme
- e) Repeat d) until all data subcarriers are used or BER
requirements can not be satisfied

$$(\Gamma = -\ln(5BER) / 1.5)$$

Throughput Results

- Throughput using M2 models, all airports, perfect CE



Summary

- Presented “worst case” channel models for different airport sizes
 - Multiple models presented for each airport
 - Compared stationary and non-stationary model implementations
- Simulated BER performance of 802.16e using “worst case” channel models
 - Analyzed performance of different channel estimation techniques for these channel models
- Simulated throughput performance of 802.16e using “worst case” channel models of different airports using an “aggressive” scheduling algorithm

Future Work

- Complete BER and throughput performance evaluations for channel models of other regions, e.g., NLOS-S and LOS-O
- Evaluate performance enhancement techniques, e.g., diversity antennas
- Implement initial WiMax wireless network “test-bed” to measure performance